The University of Osaka
Institutional Knowledge Archive

Title	Accuracy of New-Generation Intraocular Lens Power Calculation Formulas for Highly Myopic Eyes: A Multicenter Study in Japan
Author(s)	Kinoshita, Masaki; Goto, So; Mori, Yosai et al.
Citation	American Journal of Ophthalmology. 2025, 280, p. 390-398
Version Type	VoR
URL	https://hdl.handle.net/11094/102868
rights	This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.
Note	

The University of Osaka Institutional Knowledge Archive : OUKA

https://ir.library.osaka-u.ac.jp/

The University of Osaka

Accuracy of New-Generation Intraocular Lens Power Calculation Formulas for Highly Myopic Eyes: A Multicenter Study in Japan

MASAKI KINOSHITA, SO GOTO, YOSAI MORI, HIDEMASA TORII, YUMI HASEGAWA, TAKASHI KOJIMA, KAZUTAKA KAMIYA, TAKUYA SHIBA, AND KAZUNORI MIYATA

• PURPOSE: To compare the refractive prediction accuracy of 13 intraocular lens (IOL) power calculation formulas, including 7 new-generation formulas available on the European Society of Cataract and Refractive Surgeons (ESCRS) calculator, in highly myopic eyes with axial lengths (AL) of 26.0 mm or longer, through a multicenter study in Japan.

• DESIGN: A retrospective case series.

• SUBJECTS: The study included 326 eyes of 326 patients at 4 surgical sites in Japan.

• METHODS: All patients underwent comprehensive preoperative ophthalmic evaluations, including slit-lamp examination and fundoscopy by ophthalmologists. Corrected distance visual acuity and intraocular pressure were assessed by certified orthoptists. Standard phacoemulsification with intraocular lens implantation in the capsular bag was performed under topical anesthesia by experienced cataract surgeons.

• MAIN OUTCOME MEASURES: Postoperative spherical equivalent prediction error (SEQ-PE) was assessed for 13 formulas, including traditional formulas (Haigis, Hoffer Q, Holladay 1, SRK/T, Wang-Koch (WK) adjustment formulas for Holladay 1 [Holladay 1 WK] and SRK/T [SRK/T WK]) and new-generation formulas (Barrett Universal II, EVO 2.0, Hill-RBF, Hoffer QST, Kane, Cooke K6, Pearl-DGS). Predictive performance was evaluated using root-mean-square absolute error (RMSAE) and the Eyetemis online analysis tool.

• RESULTS: The mean AL was 27.28 ± 0.98 mm. The Hoffer QST, Holladay 1 WK, and SRK/T WK demonstrated myopic shifts, whereas other formulas showed a hyperopic shift in SEQ-PE. The Haigis, Hoffer Q, and Holladay 1 exhibited relatively large hyperopic errors (≥0.27 D). RMSAE exceeded 0.7 in the Hoffer Q and Holladay 1, whereas the best performance (RMSAE <0.53) was observed in the Holladay 1 WK and 6 new-generation formulas, except for the Pearl-DGS.

• CONCLUSIONS: New-generation IOL power calculation formulas and the Holladay 1 WK offer superior predictive accuracy in highly myopic eyes compared with traditional formulas. (Am J Ophthalmol 2025;280: 390–398. © 2025 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC license (http://creativecommons.org/licenses/by-nc/4.0/))

This invited article was submitted as part of the Cataract and Refractive Surgery Joint Virtual Special Issue with the Asia-Pacific Journal of Ophthalmology (APJO).

Accepted for publication August 7, 2025.

From the Department of Ophthalmology, Graduate School of Medicine, The University of Osaka, Suita, Japan.; Department of Ophthalmology (S.G.), National Hospital Organization, Tokyo Medical Center, Tokyo, Japan; Miyata Eye Hospital, Meiwakai Medical Foundation, Miyakonojo, Miyazaki, Japan; Department of Ophthalmology (H.T.), Keio University School of Medicine, Tokyo, Japan; Department of Ophthalmology, Faculty of Medicine (Y.H.), University of Tsukuba, Tsukuba, Ibaraki, Japan; Nagoya Eye Clinic (T.K.), Nagoya, Aichi, Japan; School of Allied Health Sciences, Visual Physiology (K.K.), Kitasato University, Sagamihara, Kanagawa, Japan; Roppongi Shiba Eye Clinic, J&B Medical Corporation, Minato-ku, Tokyo, Japan

Inquiries to So Goto, Department of Ophthalmology, Osaka University Graduate School of Medicine, Osaka, Japan; e-mail: gotoso@ophthal.med.osaka-u.ac.jp

INTRODUCTION

The outcomes of cataract surgery have improved greatly over recent decades due to advances in preoperative biometry technology, intraocular lens (IOL) power calculation formulas, and innovations in surgical techniques and equipment, such as small-incision procedures and high-performance devices.[1,2] In preoperative biometry, optical biometry for axial length (AL) measurement using swept-source optical coherence tomography (SS-OCT), introduced in 2014, has achieved superior reproducibility and success rates.[3,4] For IOL power calculation formulas, new-generation formulas developed after 2019 have increasingly come into widespread use.[5,6]

The global prevalence of myopia was estimated to reach 34.0% by 2020, with high myopia (greater than −5.0 D) accounting for 5.2%.[7] In East Asia, the prevalence of myopia was predicted to exceed 50%. Myopia was associated with an increased risk of cataract development.[8,9] Given these points, accurate refractive prediction in cataract surgery for highly myopic eyes, characterized by ALs, is becoming increasingly important. However, the long AL eyes exhibit greater refractive prediction errors (PEs) compared to normal eyes, and these errors vary depending on the IOL power calculation formula.[10-12]

© 2025 The Authors. Published by Elsevier Inc.
This is an open access article under the CC BY-NC license
(http://creativecommons.org/licenses/by-nc/4.0/)

0002-9394/$36.00
https://doi.org/10.1016/j.ajo.2025.08.013

The European Society of Cataract and Refractive Surgeons (ESCRS) website now offers an online calculator that enables users to obtain refractive calculation results from 7 new-generation formulas with a single data input (https://iolcalculator.escrs.org/): Barrett Universal II (BUII), Emmetoropia-verifying optical 2.0 (EVO 2.0), Hill-Radial Basis Function (Hill-RBF), Hoffer QST, Kane, Cooke K6, and Pearl-DGS. Several reports have compared the predictive accuracy of formulas using the ESCRS calculator and verified the usefulness of this site.[13-17] Furthermore, a new online analysis tool has been developed to cf the predictive ability of formulas.[18] However, only a limited number of studies have employed this tool in their analyses.[14,15] Root-mean-square absolute error (RMSAE) has recently gained increasing recognition as a widely used parameter for evaluating predictive ability.[19]

The purpose of this study is to cf the predictive accuracy of various IOL power calculation formulas, including the 7 new-generation formulas available on the ESCRS calculator, in highly myopic eyes with an AL of 26 mm or more. This comparison is conducted using RMSAE and the newly developed analytical tool through a multicenter study in Japan.

METHODS

This retrospective, multicenter study was approved by the central institutional review board of Miyata Eye Hospital (Approval No.CS-392-002), which provided ethical oversight for all participating institutions. Written informed consent was waived due to the retrospective nature of the study, and an opt-out method was employed through publicly available information. The review of medical record was conducted on consecutive patients with cataract undergoing phacoemulsification surgery from September 2016 to March 2023 at 4 academic surgical centers in Japan, namely, Keio University Hospital, Tsukuba University Hospital, Tokyo Medical Center, and Miyata Eye Hospital. The inclusion criteria were: (1) eyes undergoing uneventful phacoemulsification with in-the-bag IOL implantation of a single-piece, open loop, hydrophobic acrylic foldable IOL (Vivinex iSert XY-1 IOL [Hoya Corporation; Tokyo, Japan]); (2) AL longer than 26.0 mm with preoperative ocular biometry measured using SS-OCT-based biometers (IOLMaster 700 [Carl Zeiss Meditec AG, Jena, Germany] or OA-2000 [Tomey, Nagoya, Japan]). (3) no previous ocular surgery; (4) postoperative follow-up at 1 month or later. Keratometric index of 1.3375 was used. Patients were excluded if they had intraoperative or postoperative events or their postoperative corrected distance visual acuity was worse than 20/30 at the visits at 1 month. One eye from each patient was included. If both eyes of a patient met the inclusion criteria, the first eye to undergo surgery was selected.

• **PATIENT EXAMINATIONS AND SURGICAL PROCEDURE:** All patients underwent routine preoperative ophthalmic examinations. Slit-lamp examination and fundoscopy were performed by the ophthalmologists. Corrected distance visual acuity (CDVA) using a Landolt C chart at 5 meters and intraocular pressure were measured by experienced certified orthoptists. Standard phacoemulsification surgery was performed by experienced surgeons for all patients. The surgical technique included continuous curvilinear capsulorhexis, nucleus and cortex extraction, and IOL implantation in the capsular bag. All surgical procedures were performed under topical anesthesia by several experienced surgeons with specialization in cataract surgery.

• **POSTOPERATIVE VISUAL AND REFRACTIVE EVALUATION:** Uncorrected distance visual acuity, manifest refraction, and CDVA were assessed at least 1 month after surgery. Postoperative refraction was compared with the predicted refraction obtained from Haigis, Hoffer Q, Holladay 1, SRK/T, BUII, EVO 2.0, Hill-RBF, Hoffer QST, Kane, Cooke K6, Pearl-DGS, Holladay 1 with Wang-Koch AL adjustment (Holladay 1 WK), and SRK/T WK. Holladay 1 and SRK/T formulas were calculated through Excel spread sheet. The modified Wang-Koch adjustment formulas for Holladay 1 and SRK/T were calculated with published equations.[20] The lens constants for the 7 new-generation formulas were set according to ESCRS calculator (available at https://iolcalculator.escrs.org), while the constants of the other formulas were based on the online IOL Con (available at https://iolcon.org/lensesTable.php). Data were entered into the ESCRS calculator between April 17, 2023, and May 24, 2025. The spherical equivalent prediction error (SEQ-PE) was obtained as the postoperative spherical equivalent refraction minus the predicted refractive values calculated by each formula using the implanted IOL power. Thus, a positive SEQ-PE indicates a refractive outcome that was more hyperopic than predicted. The mean SEQ-PE, the SD (SD) of SEQ-PE, and the mean absolute SEQ-PE (MAE) were calculated for each formula. The relationship between PE and both AL and keratometry (K) was also analyzed separately.

• **STATISTICAL ANALYSIS:** Statistical analyses were performed with JMP Pro vs. 14.0.0 (SAS Institute Inc.). The Shapiro–Wilk test was used to check for normality, and non-parametric tests were used non-normally distributed data. RMSAE described by Holladay et al. was used to cf the predictive accuracy of the 13 formulas.[19] The refractive outcome was adjusted to 6-meter lane when analyzed with Eyetemis. The Friedman test was used to assess the differences in MAE between formulas, followed by Scheffe ad-hoc comparison. The tr-mean of the SEQ-PE was compared with zero with the robust 1-sample t-test. Moreover, the results were compared with each other for trueness (mean SEQ-PE), precision (the SD of SEQ-PE), and accuracy (MAE) using the robust 2-sample t-test. The Cochran

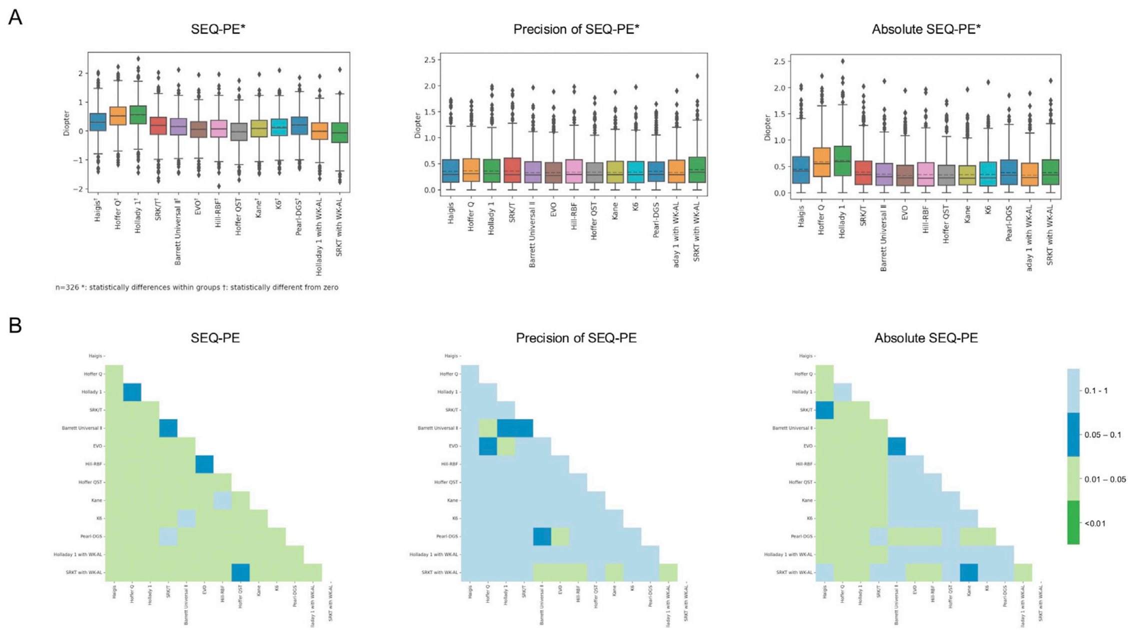

FIGURE 1. SEQ-PEs of all formulas. Box-and-whisker plot showing SEQ-PE, precision of SEQ-PE, and absolute SEQ-PE of all formulas (A). Comparison of SEQ-PE (mean), precision of SEQ-PE (SD), and absolute SEQ-PE (MAE) of all formulas (B). SEQ-PE = spherical equivalent prediction error; SD = SD; MAE = mean absolute SEQ-PE

Q test was performed to assess whether the percentage of eyes with a PE within each threshold was significantly different. If the difference was significant, the McNemar test was then utilized.[18] A *P*-value < .05 was considered statistically significant.

RESULTS

326 eyes of 326 patients (186 male [57%]) were included in this study. The mean age of the patients was 66.27 ± 9.58 years (range, 31 to 88 years). The mean AL was 27.28 ± 0.98 mm (26.00-31.32 mm), the mean keratometry was 43.66 ± 1.50 D (39.68-48.54 D), the mean ACD was 3.53 ± 0.33 mm (1.87-4.42 mm), and the mean IOL power implanted was 12.57 ± 3.04 D (6.0-19.0 D). The mean postoperative SEQ was −1.67 ± 1.17 D (−4.00 to + 1.00 D).

The refractive outcomes are presented in Table 1. SEQ-PE (mean), precision of SEQ-PE (SD), and absolute SEQ-PE (MAE) for each formula are shown in Figure 1A. The *p*-values for pairwise comparisons of the 3 parameters between formulas are presented in Figure 1B. The mean SEQ-PEs of most formulas exhibited a hyperopic shift, while myopic shifts were observed in Hoffer OST, Holladay 1 WK, and SRK/T WK. Additionally, Haigis (0.27D), Hoffer Q (0.49D), and Holladay 1 (0.52D) demonstrated relatively larger hyperopic shifts (Table 1). The tr-mean of SEQ-PE did not show a significant difference from zero in the Hoffer QST and Holladay 1 WK formulas, whereas significant differences were observed in the other formulas. In pairwise comparisons, significant differences were observed except for Holladay 1 and Hoffer Q, BUII, Hill-RBF and EVO, Kane and Hill-RBF, K6 and BUII, Pearl-DGS and SRK/T, and Hoffer QST and SRK/T WK (Figure 1B).

Regarding the precision of SEQ-PE (SD), SRK/T WK showed significant differences compared to 4 of the new-generation formulas and Holladay 1 WK (Figure 1B). Significant differences were also observed between Hoffer Q and BUII and between Holladay 1 and EVO, but no significant differences were found in any other comparisons (Figure 1B).

For absolute SEQ-PE (MAE), Holladay 1 (0.61D) and Hoffer Q (0.58D) had large values (Table 1, Figure 1A), and pairwise comparisons showed significant differences between these 2 formulas and all other formulas except for each other (Figure 1B). The Haigis (0.44D), SRK/T (0.39D), Pearl-DGS (0.39D), and SRK/T WK (0.39D) formulas exhibited relatively high absolute SEQ-PE values (Table 1). In pairwise comparisons with the other 7 formulas that showed lower absolute SEQ-PEs, the Haigis and SRK/T demonstrated statistically significant differences with all 7 formulas, the Pearl-DGS with 5 formulas, and the SRK/T WK with 3 formulas (Figure 1B). No statistically significant differences were found among the 7 formulas with lower absolute SEQ-PEs (Figure 1B).

For the percentage of eyes with absolute SEQ-PE within 0.25 D and 0.50 D of the predicted refraction, the Hoffer Q formula (20%, 45%) and Holladay 1 formula (19%,

TABLE 1. Values of SEQ-PE (mean error), Precision of SEQ-PE (SD), and Absolute SEQ-PE (Mean Absolute Error) of Each Formula

Statistic	Formula	Tr-mean	Mean	SD	Rms	Min	10%	25%	50%	75%	90%	Max
SEQ-PE	BUII	0.158	0.156	0.513	0.535	−1.457	−0.417	−0.137	0.153	0.433	0.813	2.123
SEQ-PE	EVO	0.057	0.053	0.511	0.513	−1.527	−0.522	−0.224	0.053	0.313	0.693	1.943
SEQ-PE	Haigis	0.307	0.303	0.552	0.629	−1.397	−0.352	0.013	0.303	0.601	0.988	2.033
SEQ-PE	Hill-RBF	0.076	0.073	0.523	0.527	−1.907	−0.552	−0.217	0.073	0.371	0.753	1.963
SEQ-PE	Hoffer Q	0.523	0.519	0.551	0.756	−1.167	−0.122	0.216	0.518	0.831	1.203	2.223
SEQ-PE	Hoffer QST	−0.024	−0.031	0.522	0.522	−1.687	−0.642	−0.327	−0.032	0.263	0.593	1.743
SEQ-PE	Holladay 1 WK	−0.008	−0.015	0.515	0.515	−1.647	−0.632	−0.297	−0.017	0.283	0.633	1.893
SEQ-PE	Holladay 1	0.556	0.554	0.573	0.796	−1.437	−0.112	0.243	0.573	0.863	1.233	2.503
SEQ-PE	K6	0.129	0.13	0.517	0.532	−1.447	−0.472	−0.164	0.103	0.413	0.818	2.103
SEQ-PE	Kane	0.083	0.078	0.512	0.517	−1.477	−0.532	−0.207	0.093	0.371	0.738	1.963
SEQ-PE	Pearl-DGS	0.203	0.201	0.528	0.565	−1.297	−0.392	−0.117	0.208	0.483	0.868	1.853
SEQ-PE	SRK/T	0.184	0.174	0.565	0.59	−1.727	−0.497	−0.117	0.193	0.471	0.858	2.023
SEQ-PE	SRK/T WK	−0.056	−0.065	0.563	0.566	−1.757	−0.777	−0.397	−0.067	0.283	0.618	2.133
Precision of SEQ-PE	BUII	0.332	0.381	0.342	0.512	0.004	0.034	0.135	0.286	0.535	0.879	1.966
Precision of SEQ-PE	EVO	0.329	0.38	0.341	0.51	0.003	0.053	0.133	0.273	0.522	0.877	1.887
Precision of SEQ-PE	Haigis	0.355	0.412	0.366	0.551	0.003	0.06	0.147	0.295	0.577	0.927	1.727
Precision of SEQ-PE	Hill-RBF	0.339	0.39	0.348	0.522	0.003	0.043	0.134	0.293	0.576	0.853	1.983
Precision of SEQ-PE	Hoffer Q	0.364	0.416	0.361	0.55	0.001	0.05	0.159	0.309	0.597	0.911	1.701
Precision of SEQ-PE	Hoffer QST	0.338	0.391	0.346	0.521	0.003	0.053	0.139	0.287	0.517	0.902	1.767
Precision of SEQ-PE	Holladay 1 WK	0.335	0.385	0.341	0.514	0.001	0.045	0.139	0.289	0.567	0.845	1.901
Precision of SEQ-PE	Holladay 1	0.361	0.422	0.386	0.572	0.002	0.048	0.148	0.312	0.581	0.955	1.992
Precision of SEQ-PE	K6	0.34	0.388	0.34	0.516	0.004	0.046	0.136	0.29	0.542	0.854	1.974
Precision of SEQ-PE	Kane	0.334	0.385	0.336	0.511	0.001	0.061	0.131	0.289	0.547	0.871	1.881
Precision of SEQ-PE	Pearl-DGS	0.353	0.403	0.342	0.528	0	0.07	0.16	0.295	0.53	0.94	1.65
Precision of SEQ-PE	SRK/T	0.357	0.418	0.379	0.564	0	0.06	0.14	0.29	0.605	0.95	1.91
Precision of SEQ-PE	SRK/T WK	0.383	0.431	0.361	0.562	0.001	0.07	0.141	0.341	0.627	0.936	2.189
Absolute SEQ-PE	BUII	0.356	0.406	0.349	0.535	0.003	0.057	0.144	0.303	0.559	0.957	2.123
Absolute SEQ-PE	EVO	0.332	0.384	0.341	0.513	0.003	0.053	0.137	0.283	0.524	0.87	1.943
Absolute SEQ-PE	Haigis	0.443	0.492	0.392	0.629	0.003	0.072	0.183	0.413	0.683	1.055	2.033
Absolute SEQ-PE	Hill-RBF	0.344	0.396	0.349	0.527	0.003	0.057	0.133	0.278	0.573	0.875	1.963
Absolute SEQ-PE	Hoffer Q	0.584	0.626	0.425	0.756	0.003	0.123	0.311	0.553	0.853	1.203	2.223
Absolute SEQ-PE	Hoffer QST	0.339	0.391	0.346	0.522	0.003	0.06	0.143	0.285	0.524	0.903	1.743
Absolute SEQ-PE	Holladay 1 WK	0.335	0.386	0.341	0.515	0.003	0.047	0.137	0.29	0.562	0.843	1.893
Absolute SEQ-PE	Holladay 1	0.613	0.659	0.448	0.796	0.003	0.142	0.326	0.593	0.883	1.275	2.503
Absolute SEQ-PE	K6	0.35	0.398	0.353	0.532	0.003	0.047	0.133	0.285	0.581	0.935	2.103
Absolute SEQ-PE	Kane	0.343	0.392	0.337	0.517	0.003	0.065	0.153	0.28	0.512	0.883	1.963
Absolute SEQ-PE	Pearl-DGS	0.386	0.434	0.362	0.565	0.007	0.047	0.157	0.333	0.621	1.018	1.853
Absolute SEQ-PE	SRK/T	0.393	0.448	0.384	0.59	0.003	0.067	0.154	0.343	0.603	0.995	2.023
Absolute SEQ-PE	SRK/T WK	0.385	0.434	0.363	0.566	0.003	0.063	0.157	0.338	0.626	0.96	2.133

BUII= Barrett Universal II; EVO = Emmetoropia-verifying optical 2.0; Hill-RBF = Hill-Radial Basis Function; K6 = Cooke K6; SEQ-PE = spherical equivalent prediction error.

All values are expressed in diopters.

40%) showed the lowest values, with the Haigis formula (31%, 58%) also being relatively low. In comparisons with the other ten formulas, both the Hoffer Q and Holladay 1 showed significantly lower percentages than all ten, while the Haigis showed statistically significant differences with 6 formulas within 0.25 D and with 8 formulas within 0.50 D. For the percentages within 0.75 D and 1.00 D, the Hoffer Q (66%, 83%) and Holladay 1 (64%, 81%) again showed low values. Within 0.75 D, both formulas had significantly lower percentages than all of the other eleven formulas. Within 1.00 D, the Hoffer Q showed significantly lower percentages compared to all formulas except the Haigis and SRK/T, while the Holladay 1 differed significantly only from the Haigis.

RMSAE values exceeded 0.7 for the Holladay 1 and Hoffer Q and exceeded 0.6 for the Haigis (Table 2), while all other formulas had values in the 0.5 range. In particular, the Holladay 1 WK and the 6 new-generation formulas excluding the Pearl-DGS had RMSAE values below 0.53. Figure 2

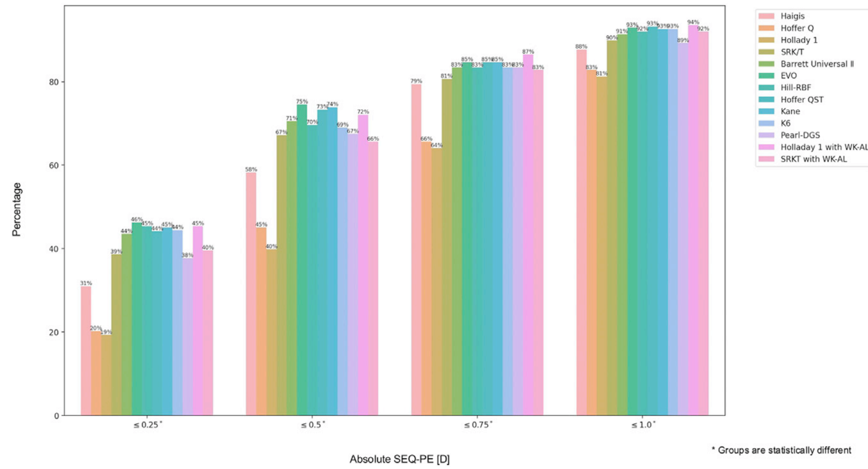

FIGURE 2. Percentage of eyes with an absolute SEQ-PE within 0.25 D, 0.50 D, 0.75 D, and 1.00 D for each formula. SEQ-PE = spherical equivalent prediction error.

TABLE 2. Values of Root-Mean-Square Absolute Error of Each Formula in Ascending Order

Formula	RMSAE
EVO	0.510
Kane	0.512
Holladay 1 WK	0.516
Hill-RBF	0.523
K6	0.525
Hoffer QST	0.525
BUII	0.526
Pearl-DGS	0.554
SRK/T WK	0.570
SRK/T	0.581
Haigis	0.614
Hoffer	0.734
Holladay 1	0.774

BUII = Barrett Universal II; EVO = Emmetoropia-verifying optical 2.0; Hill-RBF = Hill-Radial Basis Function; K6 = Cooke K6; RMSAE = root-mean-square absolute error.

Table 3 shows the results of the simple regression analysis between SEQ-PE and both AL and K. Figures 3 and 4 illustrate the relationship between SEQ-PE and both AL and K, respectively. In traditional formulas, a longer AL was associated with an increased hyperopic shift (Figure 3), and a significant positive correlation was observed in 3 of the 4 traditional formulas, excluding the Haigis (Table 3). In contrast, the Hill-RBF and SRK/T WK demonstrated a significant negative correlation with AL (Table 3). Regarding K, both the Hoffer Q and Pearl-DGS exhibited a significant increase in hyperopic shift with higher K values, and the Haigis and Hoffer QST also showed a positive correlation, though not statistically significant (Table 3). In the remaining 9 formulas, an increase in K was associated with a reduction in hyperopic shift (or an increase in myopic shift), with the Holladay 1, SRK/T, and SRK/T WK showing significant negative correlations.

DISCUSSION

This study compared and evaluated the refractive predictive accuracy of 13 IOL power calculation formulas, including 7 new-generation formulas, in highly myopic eyes with an AL of 26 mm or more at multiple institutions in Japan using IOLMaster 700 or OA-2000. It has been previously reported that these SS-OCT-based biometers show no significant differences in measurements of AL and mean K.[21] The relationships between PE and both AL and K were also investigated. While many formulas resulted in values close to zero or a hyperopic shift, Hoffer QST and 2 formulas with the modified WK adjustment of AL showed a myopic shift. The Holladay 1 WK and new-generation formulas except for Pearl-DGS demonstrated higher predictive accuracy than the traditional formulas, Pearl-DGS, and SRK/T WK. Except for a few formulas, most formulas exhibited greater hyperopic shifts as AL increased and as K decreased.

Evaluating the predictive performance of IOL power calculation formulas is important. In cases where a mean PE cannot be assumed to be zero, such as in long eyes, short eyes, or post-corneal refractive surgery eyes, RMSAE and MAE are useful, with RMSAE being more sensitive to outliers than MAE.[19] Additionally, because AE does not follow a normal (Gaussian) distribution, median AE is often used. Furthermore, an online tool, Eyetemis, has been developed to assess trueness (mean), precision (SD), and accuracy (MAE) while also providing the percentage of eyes within AE predefined thresholds.[18] This tool has enabled more de-

TABLE 3. Relationship Between Prediction Error and Axial Length and Keratometry

	Axial Length					Keratometry				
	β	*P*-value	Lower 95%	Upper 95%	R	β	*P*-value	Lower 95%	Upper 95%	R
Haigis	0.052	.095	−0.009	0.114	0.093	0.037	.070	−0.003	0.077	0.100
Hoffer	0.154	<.001	0.095	0.214	0.273	0.072	<.001	0.033	0.112	0.196
Holladay 1	0.256	<.001	0.198	0.313	0.436	−0.061	.004	−0.103	−0.020	0.161
SRK/T	0.128	<.001	0.066	0.190	0.221	−0.144	<.001	−0.182	−0.106	0.382
BU II	0.001	.966	−0.056	0.059	0.002	−0.006	.766	−0.043	0.032	0.016
EVO	0.019	.511	−0.038	0.076	0.036	−0.007	.712	−0.044	0.030	0.021
Hill-RBF	−0.064	.030	−0.122	−0.006	0.120	−0.032	.098	−0.070	−0.006	0.092
Hoffer QST	0.010	.745	−0.049	0.068	0.018	0.004	.853	−0.034	0.042	0.010
Kane	−0.022	.443	−0.079	0.035	0.043	−0.018	.350	−0.055	0.020	0.052
Cooke K6	−0.027	.358	−0.085	0.031	0.051	−0.004	.822	−0.042	0.033	0.012
Pearl DGS	0.033	.271	−0.026	0.092	0.061	0.062	.002	0.024	0.099	0.17
Holladay 1 WK	−0.049	.092	−0.107	0.008	0.093	−0.026	.170	−0.064	0.011	0.076
SRK/T WK	−0.12	<.001	−0.182	−0.059	0.209	−0.115	<.001	−0.154	−0.076	0.307

BUII= Barrett Universal II; EVO = Emmetoropia-verifying optical 2.0; Hill-RBF = Hill-Radial Basis Function; β = regression coefficients; R = correlation coefficients.

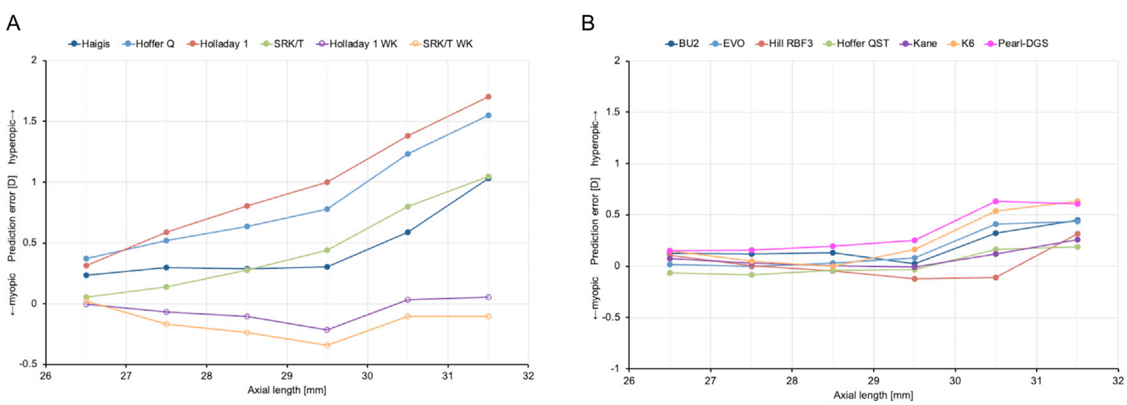

FIGURE 3. Prediction error vs axial length (in millimeters) using traditional vergence formulas and both Holladay 1 and SRK/T with Wang-Koch adjustment (A) and new-generation formulas available on the European Society of Cataract and Refractive Surgeons (ESCRS) calculator (B). Holladay 1 WK = Holladay 1 with modified Wang-Koch adjustment; SRK/T WK = SRK/T with modified Wang-Koch adjustment.

tailed and accessible evaluations of predictive performance for each formula. Indeed, several studies have demonstrated its usefulness in comparing multiple IOL formulas using Eyetemis.[14,15] In this study, we evaluated formula performance comprehensively using both RMSAE and Eyetemis analyses.

Many studies have reported that new-generation formulas exhibit higher predictive accuracy than traditional formulas in highly myopic eyes.[22,23] Consistent with previous reports, this study found that new-generation formulas generally outperformed traditional formulas in terms of absolute SEQ-PE and RMSAE. However, Pearl-DGS showed lower performance compared to the other 5 new-generation formulas. Pearl-DGS has been reported to have overall predictive accuracy comparable to other next-generation formulas.[24,25] However, in eyes with long AL, the Pearl-DGS formula has been reported to yield a greater MAE relative to other contemporary intraocular lens power calculation formulas.[26]

Figure 3 demonstrates that a longer AL tends to be associated with an increased hyperopic shift, particularly in traditional IOL power calculation formulas. In contrast, Hill-RBF and SRK/T WK showed a significant negative correlation with AL. Figure 4 indicates Hoffer Q and Pearl-DGS showed a significant increase in hyperopic shift with higher K values. On the other hand, an increase in K was associated with a significant decrease in hyperopic shift (or a significant increase in myopic shift), in Holladay 1, SRK/T,

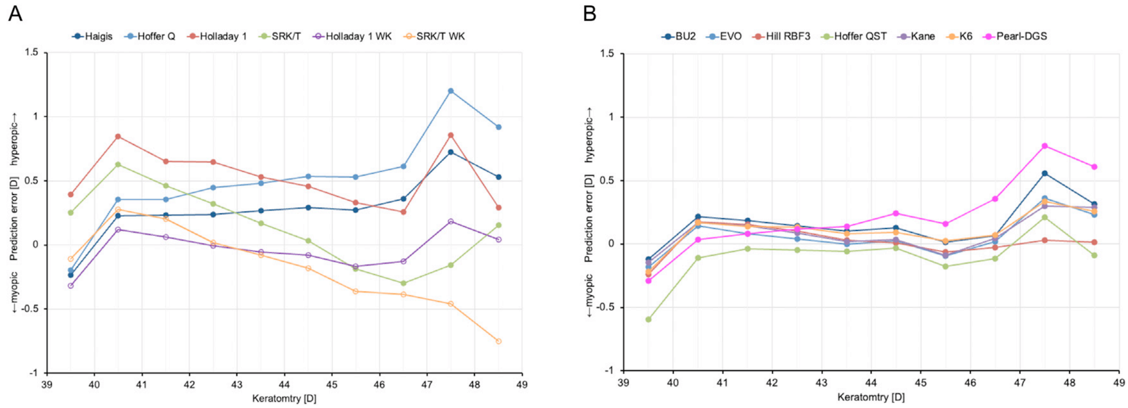

FIGURE 4. Prediction error vs keratometry (in diopters) using traditional vergence formulas and both Holladay 1 and SRK/T with modified Wang-Koch adjustment (A) and new-generation formulas available on the European Society of Cataract and Refractive Surgeons (ESCRS) calculator (B). Holladay 1 WK = Holladay 1 with modified Wang-Koch adjustment; SRK/T WK = SRK/T with modified Wang-Koch adjustment.

TABLE 4. Values of Axial Length, Mean Keratometry, and Anterior Chamber Depth of Each Biometer

	n	Axial Length					Mean Keratometry					Anterior Chamber Depth				
		Mean	SD	Lower 95%	Upper 95%	*P*-value	Mean	SD	Lower 95%	Upper 95%	*P*-value	Mean	SD	Lower 95%	Upper 95%	*P*-value
IOLMaster 700	137	27.31	0.95	27.15	27.47	.34	43.7	1.56	43.44	43.97	.33	3.55	0.36	3.48	3.61	.23
OA-2000	189	27.26	1	27.12	27.41		43.63	1.45	43.42	43.84		3.52	0.31	3.47	3.56	

SD = standard deviation.
Axial length and anterior chamber depth values are expressed in millimeters.
Mean keratometry values are expressed in diopters.

and SRK/T WK. Fam et al. pioneered the evaluation of the relationship between PE and AL to cf the performance of 4 traditional IOL power calculation formulas and a formula based on the original calibration of the IOLMaster.[27] Melles et al. reported associations between PE and AL/K in traditional formulas, as well as between PE and AL in new-generation formulas.[10,22] Our study confirmed similar overall trends and exceptional patterns. However, to the best of our knowledge, this may be the first report to show that Pearl-DGS exhibits an increasing hyperopic shift with increasing K.

As a countermeasure against the hyperopic shift observed with traditional formulas in highly myopic eyes, Wang et al. developed the WK adjustment.[28] A less aggressive modified WK adjustment was introduced in 2018, which we applied in this study.[18] Our study showed that while Holladay 1 WK achieved predictive accuracy comparable to new-generation formulas, SRK/T WK did not improve its performance, resulting in significantly lower accuracy than Holladay 1 WK. Several studies have compared these 2 modified WK-adjusted formulas, but none have reported significant differences in predictive accuracy.[11,29]

This study has several limitations. First, although this multicenter study allowed for the inclusion of 326 eyes with AL greater than 26.0 mm, its retrospective design may have introduced selection bias and inconsistencies in data collection. Second, the surgical techniques and biometry devices were not fully standardized across centers. However, all surgeries were performed with modern microincision cataract surgery, and implanted IOLs have the same platform manufactured by the 1 company, compatible with small incisions. Additionally, preoperative measurements were obtained using high-precision SS-OCT-based biometers: the IOLMaster 700 and the OA-2000. It has been previously reported that these SS-OCT–based biometers show no significant differences in measurements of AL and mean K.[21] In the present dataset, no significant differences in AL or K were observed between the 2 biometry devices, suggesting that their impact on IOL power calculation is clinically of limited clinical relevance (Table 4). Third, since all participants were Japanese, the findings may not be generalizable to other ethnic groups. Future studies should include more ethnically diverse populations.

In summary, this multicenter study demonstrated that new-generation IOL power calculation formulas provide significantly greater predictive accuracy than traditional formulas in eyes with long AL. Notably, the application of the modified WK adjustment to the Holladay 1 formula yielded predictive performance comparable to that of new-generation methods. Furthermore, traditional formulas displayed a tendency toward hyperopic PE with increasing AL, whereas SRK/T WK exhibited a myopic shift. Lastly, although the influence of corneal curvature on PE varied by formula, traditional formulas, Pearl-DGS, and SRK/T WK were more affected by bias influenced by K value.

Funding/Support: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
Financial Disclosures: The authors indicate no financial support or conflicts of interest. All authors attest that they meet the current ICMJE criteria for authorship.
Ethics Approval: This surveillance study was approved by the Institutional Review Board of Miyata Eye Hospital (Miyazaki, Japan). The identifier was CS-392-002. It was performed following the tenets of the Declaration of Helsinki.
Consent to Participate: Written informed consent was waived due to the retrospective nature of the study, and an opt-out method was employed through publicly available information.
Data Availability: The data and the material supporting findings of this study are available from the corresponding author upon reasonable request.
Acknowledgments: The authors thank Tadatoshi Tokunaga, CO, (Orthoptists of Miyata Eye Hospital), Keiko Ogawa, CO, Saori Sugiyama, CO, and Maki Matsumaru, CO, (Orthoptists of National Hospital Organization, Tokyo Medical Center), Yuta Shigeno, CO, Saki Obana, CO, and Haruna Togawa, CO, (Orthoptists of Keio University), Naoki Isogai, CO, Tomoya Nishida, CO, (Orthoptists of Nagoya Eye Clinic) for their assistance with data collection.

REFERENCES

1. Kane JX, Chang DF. Intraocular lens power formulas, biometry, and intraoperative aberrometry: a review. *Ophthalmology*. 2020:1–21.
2. Goto S, Maeda N. Corneal topography for intraocular lens selection in refractive cataract surgery. *Ophthalmology*. 2021;128:e142–e152.
3. McAlinden C, Wang Q, Gao R, et al. Axial length measurement failure rates with biometers using swept-source optical coherence tomography compared to partial-coherence interferometry and optical low-coherence interferometry. *Am J Ophthalmol*. 2017;173:64–69.
4. Kane JX, Chang DF. Intraocular lens power formulas, biometry, and intraoperative aberrometry. *Ophthalmology*. 2021;128:e94–e114.
5. Savini G, Hoffer KJ, Kohnen T. IOL power formula classifications. *J Cataract Refract Surg*. 2024;50:105–107.
6. Stopyra W, Langenbucher A, Grzybowski A. Intraocular lens power calculation formulas: a systematic review. *Ophthalmol Ther*. 2023;12:2881–2902.
7. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology*. 2016;123:1036–1042.
8. Flitcroft DI. The complex interactions of retinal, optical and environmental factors in myopia aetiology. *Prog Retin Eye Res*. 2012;31:622–660.
9. Kanthan GL, Mitchell P, Rochtchina E, et al. Myopia and the long-term incidence of cataract and cataract surgery: the blue mountains eye study. *Clin Exp Ophthalmol*. 2014;42:347–353.
10. Melles RB, Holladay JT, Chang WJ. Accuracy of intraocular lens calculation formulas. *Ophthalmology*. 2018;125:169–178.
11. Zhang J, Tan X, Wang W, et al. Effect of axial length adjustment methods on intraocular lens power calculation in highly myopic eyes. *Am J Ophthalmol*. 2020;214:110–118.
12. Goto S, Maeda N, Uehara K, et al. Effect of segmented optical axial length on the performance of new-generation intraocular lens power calculation formulas in extremely long eyes. *J Clin Med*. 2023;12:1–9.
13. Janusz S, Douglas KD, Li W. Performance of formulas included in the ESCRS intraocular lens power calculator. *J Cataract Refract Surg*. 2024;50:1224–1229.
14. Whang WJ, Koh K, Hoffer KJ, et al. Comparison of intraocular lens power formulas for negative-diopter intraocular lens implantation for high myopia. *J Cataract Refract Surg*. 2024:119–125.
15. Sorkin N, Zadok R, Totah H, et al. Analysis of the ESCRS calculator's prediction accuracy. *J Cataract Refract Surg*. 2024:1109–1116.
16. Lwowski C, Kohnen T. Prospective evaluation of the ESCRS online calculator for calculation of a multifocal intraocular lens. *J Cataract Refract Surg*. 2023;49(12):1209–1215.
17. Lwowski C, Wenner Y, Kaiser KP, et al. Intraocular lens calculation using the ESCRS online calculator in pediatric eyes undergoing lens extraction. *J Cataract Refract Surg*. 2024;50(7):676–681.
18. Kan-Tor Y, Abulafia A, Zadok D, et al. Spherical equivalent prediction analysis in IOL power calculations using Eyetemis, a comprehensive approach. *J Cataract Refract Surg*. 2024:1128–1134.
19. Holladay JT, Wilcox RR, Koch DD, Wang L. Statistics of prediction error for non-gaussian dependent and independent datasets. *J Cataract Refract Surg*. 2023;49:440–442.
20. Wang L, Koch DD. Modified axial length adjustment formulas in long eyes. *J Cataract Refract Surg*. 2018;44:1396–1397.
21. Liao X, Peng Y, Liu B, et al. Agreement of ocular biometric measurements in young healthy eyes between IOLMaster 700 and OA-2000. *Sci. Rep.*. 2020;10:3134.
22. Melles RB, Kane JX, Olsen T, Chang WJ. Update on intraocular lens calculation formulas. *Ophthalmology*. 2019;126:1334–1335.
23. Li H, Ye Z, Luo Y, Li Z. Comparing the accuracy of the new–generation intraocular lens power calculation formulae in axial myopic eyes: a meta-analysis. *Int Ophthalmol*. 2022.
24. Debellemanière G, Dubois M, Gauvin M, et al. The PEARL-DGS formula: the development of an open-source machine learning–based thick IOL calculation formula. *Am J Ophthalmol*. 2021;232:58–69.
25. Shammas HJ, Taroni L, Pellegrini M, et al. Accuracy of newer intraocular lens power formulas in short and long eyes using sum-of-segments biometry. *J Cataract Refract Surg*. 2022;48:1113–1120.
26. Hipólito-Fernandes D, Luís ME, Gil P, et al. Vrf-g, a new intraocular lens power calculation formula: a 13-formulas comparison study. *Clin Ophthalmol*. 2020;14:4395–4402.

27. Fam HB, Lim KL. Improving refractive outcomes at extreme axial lengths with the IOLMaster: the optical axial length and keratometric transformation. *Br J Ophthalmol*. 2009;93:678–683.
28. Wang L, Shirayama M, Ma XJ, et al. Optimizing intraocular lens power calculations in eyes with axial lengths above 25.0 Mm. *J Cataract Refract Surg*. 2011;37:2018–2027.
29. Liu J, Wang L, Chai F, et al. Comparison of intraocular lens power calculation formulas in Chinese eyes with axial myopia. *J Cataract Refract Surg*. 2019;45:725–731.